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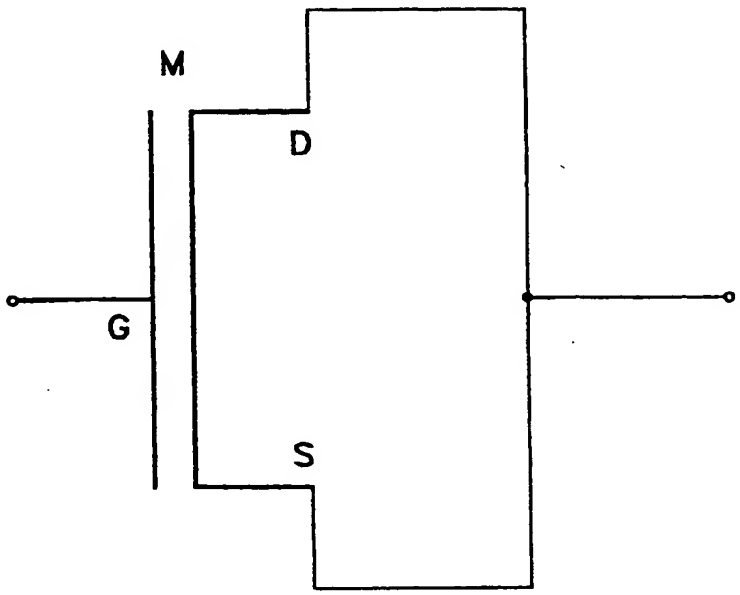
(54) Title: A BAND-SWITCHED INTEGRATED VOLTAGE CONTROLLED OSCILLATOR



(57) Abstract: The source to drain capacitance of a FET device is used by connecting the source and drain together electrically so as to form a two terminal capacitive device which may be switched into and out of a parallel resonant circuit. Thus, sets of FET devices with their sources and drains connected together are employed in a circuit which produces an output voltage signal at a frequency which is tunable within a plurality of different individual bands. The resultant voltage controlled oscillator is particularly useful in cellular telephone and related wireless systems and/or in any other situation where integrated high frequency voltage control oscillator circuits are desired.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A BAND-SWITCHED INTEGRATED VOLTAGE CONTROLLED OSCILLATOR

The present invention is generally directed to voltage controlled oscillator components and circuits. More particularly, the present invention is directed to a band- switched integrated voltage controlled oscillator employing field effect transistors as circuit elements whose capacitance varies as a function of applied voltage. Even more particularly, the present invention is directed to voltage controlled oscillator circuits which are particularly useful in frequency synthesizers and even more particularly useful in cellular telephone systems and devices.

Voltage controlled oscillators (VCOs) are commonly used in wireless electronic equipment, and elsewhere, as part of the frequency synthesizer systems. However, these circuits have so far resisted incorporation into integrated circuit devices. In virtually every cellular telephone, these circuits are built with discrete components. However, the discrete design poses many problems for designer of such systems.

In particular, the discrete components are physically large. Additionally, operation at high frequency is often very difficult or impossible due to the presence of parasitic effects produced by discrete sized components. Additionally, the cost for the discrete components, both in terms of their individual cost and the cost of assembly is high.

VCO circuits have been very hard to produce in integrated circuit form for several reasons. In particular, these circuits require variable reactors. In particular, capacitors have been seen to be considered as essential components of any VCO circuits. However, the standard integrated circuit manufacturing processes are not optimized or designed to produce such devices and in situations where they are produced, the quality of the on chip components is poor. In particular, integrated varactors have been seen to be both lossy and non linear.

Applications for voltage controlled oscillators are essentially universal in nature. VCOs are considered to be basic system component building blocks. These circuits may be found in disk drives, in wireless cellular telephones and in any other systems in which it is desired to control oscillation frequency by means of an applied tuning voltage.

The present invention accordingly provides, in a first aspect, a two-terminal capacitor comprising a field effect transistor having a source, a Gate and a drain and electrical connections thereto wherein said source and drain are thereby electrically connected together to provide a first terminal of said capacitor, said Gate connection providing said second terminal.

Preferably, in a capacitor according to the first aspect, the transistor is a MOSFET.

The present invention provides, in a second aspect, a voltage controlled tuning circuit comprising a resonant circuit including a capacitor; a plurality of pairs of capacitive elements with at least one of said capacitive elements comprising a FET device with its source and drain connected together to form one terminal of a two terminal capacitive element with the base of said FET device being the second terminal of said at least one capacitive element, with each of said members of said pairs being connected in series, and with said pairs of capacitive elements being connected in parallel with the capacitor in said resonant circuit; and means for varying the capacitance of selected ones of said pairs of elements.

In a circuit according to the second aspect, said varying means preferably comprises circuits for applying voltage to select ones of said Gates.

Preferably in a circuit according to the second aspect, each one of said pairs comprises FET devices.

In accordance with a preferred embodiment of the present invention a field effect transistor is employed as a variable capacitance device. In order to achieve this function from a field effect transistor, the source and drain of this device are electrically connected together to provide a first terminal of a two terminal capacitor. The Gate preferably provides the other terminal.

In accordance with yet another embodiment of the present invention a voltage controlled tuning circuit comprises a resonant circuit which includes a capacitor together with a plurality of pairs of capacitive elements. Each of the capacitive elements is formed from a field effect

transistor with its source and drain electrically connected together operating in effect as a variable capacitor in the manner described in the paragraph above. The plurality of pairs of capacitive elements are connected in parallel with the first capacitor. Means are provided for varying the effective capacitance of selected ones of the pairs of capacitive elements. In this way various ones of the capacitive element pairs may be switched into or out of a desired capacitive state. For example, by the inclusion of four such pairs, a four bit input preferably provides a selection of up to 16 different bands.

Accordingly, the present invention preferably provides an improved voltage controlled oscillator. The present invention utilizes the characteristics of FET devices in such a manner that they can be used as variable capacitors.

The present invention preferably provides a voltage controlled oscillator circuit which may be integrated on a circuit chip in accordance with standard integrated circuit fabrication processes.

The present invention preferably provides an integrated variable capacitor which is not lossy but which advantageously provides a linear response.

The present invention preferably provides voltage controlled oscillator circuits which are particularly useful in wireless electronic equipment and even more particularly useful in cellular telephones and cellular telephone systems.

The present invention preferably provides a voltage controlled oscillator circuit which exhibits high frequency operational characteristics but which is relatively immune to parasitic effects.

The present invention preferably provides a relatively low cost voltage controlled oscillator.

The present invention alleviates the problem associated with the poor quality of on-chip integrated circuit components which would otherwise be required.

The present invention preferably provides a voltage controlled oscillator circuit which may be switched into and out of a plurality of different frequency bands.

In addition, the present invention preferably provides a high performance voltage controlled oscillator in an integrated circuit package.

A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating the utilization of a field effect transistor device with the source and drain connected so as to be operable as a variable capacitance circuit element;

Figure 2 is a schematic circuit diagram illustrating a voltage controlled oscillator in accordance with a preferred embodiment of the present invention which utilizes the FET/ capacitive circuit illustrated in Figure 1;

Figure 3 is a schematic diagram of an alternate version of a voltage controlled oscillator in accordance with a preferred embodiment of the present invention;

Figure 4 is a plot of frequency versus tuning voltage; and

Figure 5 is a simulated plot illustrating voltage controlled oscillator band switching such as occurs in the operation of embodiments of the present invention.

Preferred embodiments of the present invention take advantage of the fact that when the source and drain of a field effect transistor, device such as a MOSFET, are connected together, the device is operable as a variable capacitor. In particular, preferred embodiments of the present invention takes advantage of the fact that the gate to source/drain capacitance varies significantly with the applied voltage. This circuit element preferably provides several important benefits. In particular, the capacitive losses are much smaller when compared to the alternative P/N diode. Moreover, switching into capacitive mode induced by the

applied voltage is abrupt. This makes the modified FET circuit element ideal for use in digital switching circuits. In particular, it is noted that such circuits are useful where-ever voltage controlled oscillators are employed, especially in high frequency operations such as cellular telephones and/or in certain computer disk drive circuits.

A voltage controlled oscillator in accordance with a preferred embodiment of the present invention is illustrated in Figure 2. A variation is also illustrated in Figure 3. With respect to Figure 2 it is noted that transistors Q_1 and Q_0 are connected in a standard oscillator circuit with the frequency of oscillation being determined by the resonant frequency of inductors L_0, L_1 and capacitor C_8, together with a variable capacitance provided by FET devices M_1 through M_8, as shown. More particularly, four pairs of variable capacitive elements are shown. For example M_1 and M_2 comprise one such pair as do M_3 and M_4, then M_5 and M_6 and finally M_7 and M_8. In each case the FET device has its source and drain connected as illustrated in Figure 1. More particularly, through the application of band selection voltages through resistors R_4 through R_7 various levels of effective capacitance may be added to the resonant circuit which employs capacitor C_8 which thus acts as a defining lower capacitive limit for an LC resonant circuit which acts as the frequency control for the voltage controlled oscillator shown. By means of a tuning voltage applied through resistor R_8 to the junction of diodes D_0 and D_1 the capacitance of these devices is varied within the selected band.

The variation of frequency as a function of tuning voltage within a mid-band frequency range is illustrated in Figure 4. This Figure illustrates that it is possible to provide a frequency variation of approximately 50 megahertz over several frequency bands. Likewise in a sixteen band system, Figure 5 illustrates the frequency overlap amongst the various bands.

In preferred embodiments of the present invention inductors L_0 and L_1 are one nanohenry devices; capacitors C_8 is a one picofarad capacitor; capacitors R_1, R_2, R_3, R_4, R_5, R_6, R_7 and R_8 are all one kilohm devices. Likewise capacitors C_3, C_5, C_4 and C_7 are one picofarad devices. This is also true of capacitors C_6 and C_7 in Figure 4. R_9 is also a one kilohm resistor.

Accordingly, it will be appreciated by those skilled in the art that the circuit and FET utilization of the embodiments of the present invention provide the advantages indicated above for the embodiments of the present invention. In particular it will be noted that the embodiments of the present invention enable the switching of tens of bands with a single voltage control oscillator, with almost no penalty in circuit size. This is made possible by adding or subtracting capacitance in lump sum amounts thus changing the resonant frequency. By using lumps with binary weights, the band is selected directly with a single binary word without the necessity of a separate decoder circuit. In particular, it is seen that in preferred embodiments of the present invention the gate to source capacitance of an FET device is used directly and is a perfect match for the present application. More particularly the gate to source capacitance shows significant variation between the two states (when the FET is on and when it is off) and it is a low loss device exhibiting high linearity in either of these states.

CLAIMS

1. A two-terminal capacitor comprising;

a field effect transistor having a source, a Gate and a drain and electrical connections thereto wherein said source and drain are thereby electrically connected together to provide a first terminal of said capacitor, said Gate connection providing said second terminal.

2. A capacitor as claimed in Claim 1 in which said transistor is a MOSFET.

3. A voltage controlled tuning circuit comprising:

a resonant circuit including a capacitor;

a plurality of pairs of capacitive elements with at least one of said capacitive elements comprising a FET device with its source and drain connected together to form one terminal of a two terminal capacitive element with the base of said FET device being the second terminal of said at least one capacitive element, with each of said members of said pairs being connected in series, and with said pairs of capacitive elements being connected in parallel with the capacitor in said resonant circuit; and

means for varying the capacitance of selected ones of said pairs of elements.

4. A circuit as claimed in Claim 3 in which said varying means comprises circuits for applying voltage to select ones of said Gates.

5. A circuit as claimed in Claim 3 in which each one of said pairs comprises FET devices.

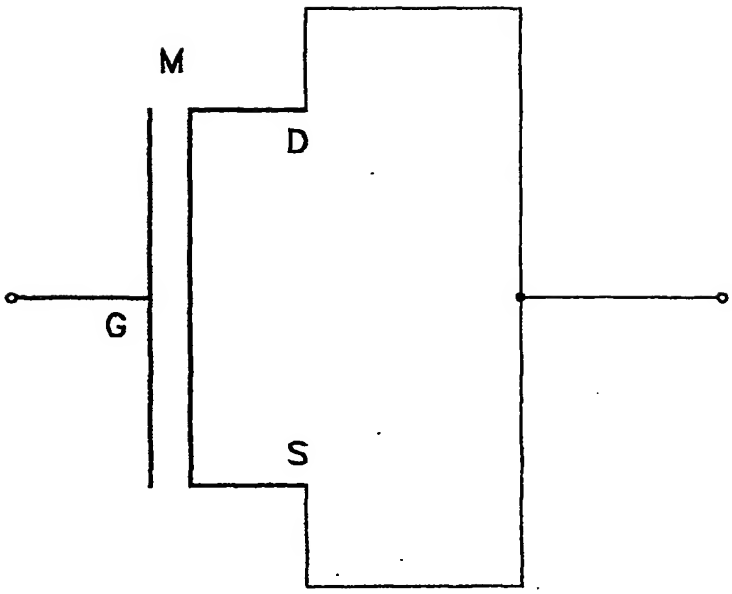


FIG. 1

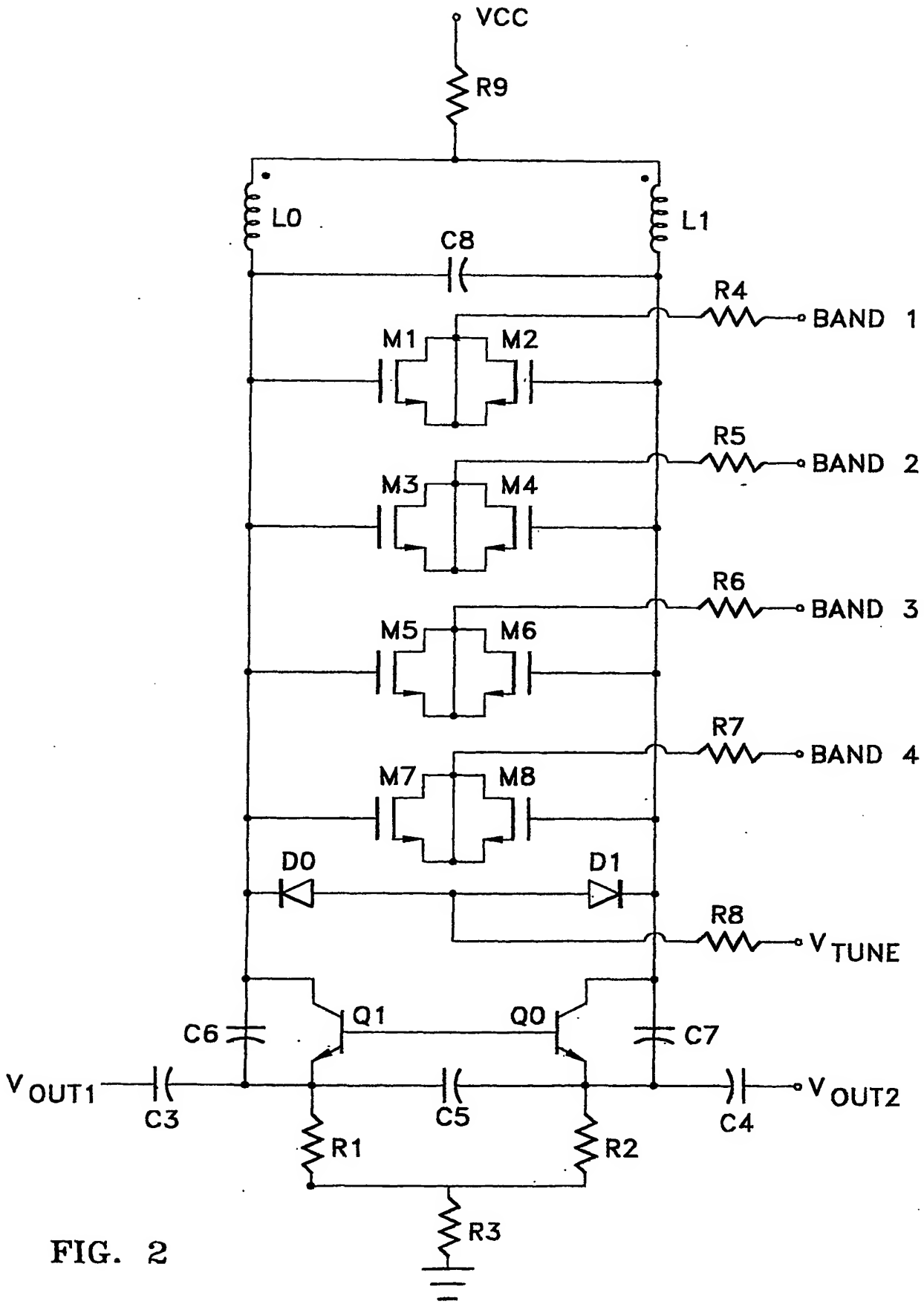
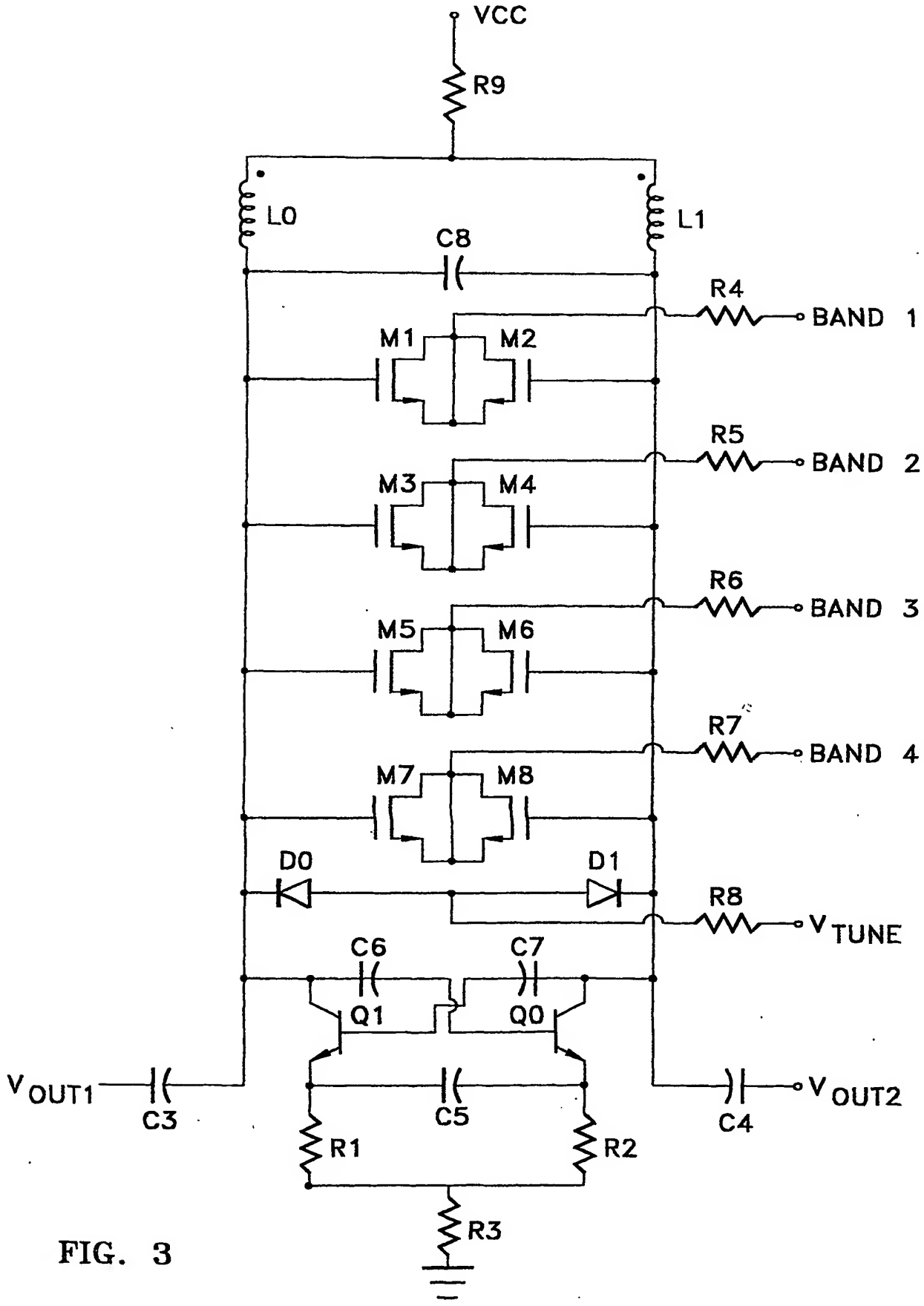

VCC
R9
L0
L1
C8
R4
BAND 1
M1
M2
R5
BAND 2
M3
M4
R6
BAND 3
M5
M6
R7
BAND 4
M7
M8
D0
D1
R8
V TUNE
C6
Q1
Q0
C7
V OUT1
C3
C5
C4
V OUT2
R1
R2
R3

FIG. 2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L0
L1
C8
R4
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M1
M2
R5
BAND 2
M3
M4
R6
BAND 3
M5
M6
R7
BAND 4
M7
M8
D0
D1
R8
V TUNE
C6
C7
Q1
Q0
V OUT1
C3
C5
C4
V OUT2
R1
R2
R3

FIG. 3

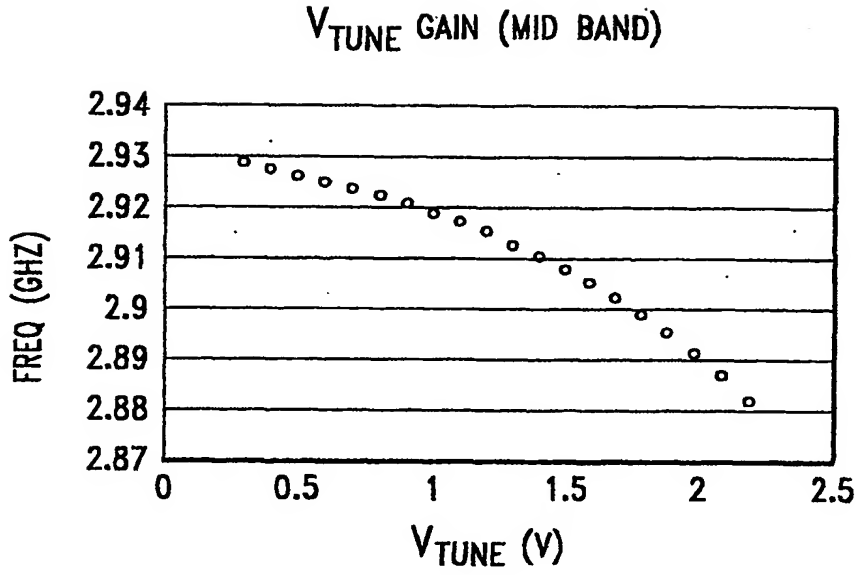
V_{TUNE} GAIN (MID BAND)
FREQ (GHZ)
2.94
2.93
2.92
2.91
2.9
2.89
2.88
2.87
0
0.5
1
1.5
2
2.5
V_{TUNE} (V)

FIG. 4

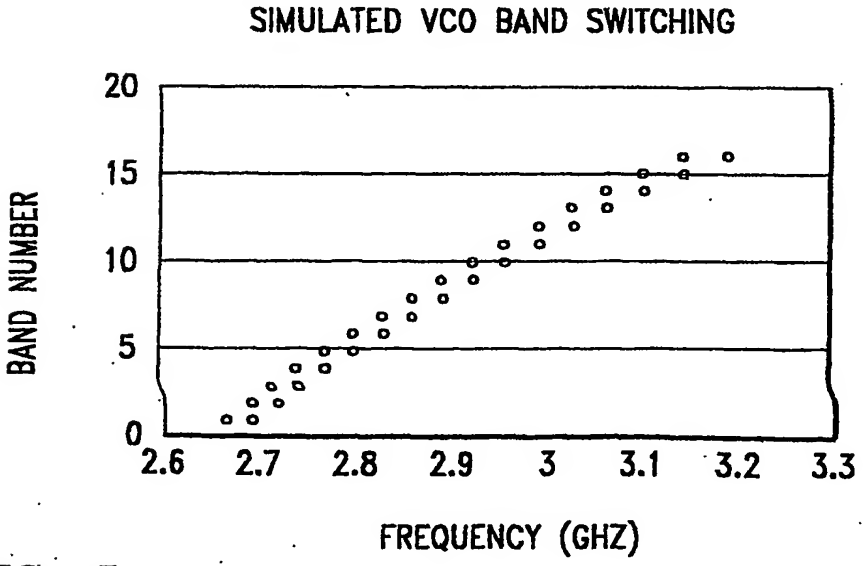
SIMULATED VCO BAND SWITCHING
BAND NUMBER
20
15
10
5
0
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
FREQUENCY (GHZ)

FIG. 5

INTERNATIONAL SEARCH REPORT

In	al Application No
	PCT/GB 01/00101

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H03B5/12 H03B7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 899 866 A (LSI LOGIC CORP) 3 March 1999 (1999-03-03) column 4, line 16 - line 41; figure 5A column 7, line 4 -column 8, line 16; figure 7	1-5

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 March 2001	27/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Beasley-Suffolk, D

INTERNATIONAL SEARCH REPORT

ormation on patent family members

Int nal Application No
PCT/GB 01/00101

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0899866 A	03-03-1999	NONE	